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SELECTING NOZZLE ARRANGEMENT OF A CHIMNEY TOWER TO REDUCE THE TEMPERATURE AND TO INCREASE THE ENTRAINMENT MASS FLOW

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ABSTRACT

The aim of this research work was to find the best arrangement of nozzles inside the chimney tower to reduce the temperature and to increase the entrainment mass flow. An existing design of the nozzle arrangement was used as the reference. Six configuration models as replacement alternatives were tested by using Computational Fluid Dynamics (CFD), an analysis tool to see the effect of different configurations to the temperature and entrainment mass flow. Some parameters were examined including temperature distribution inside the chimney in conjunction with an evaporative cooling system and the velocity flow. Prior to the analysis of other nozzle arrangements, five meshing types were tried and selected one to get the similar result with the existing design. The simulation results of new nozzle arrangement configuration with 8 nozzles at the top layer and 3 nozzles at the height of 3.5m from the base of the stack produces the optimum capacity in decreasing temperature and increasing the rate of water vapor.

***KEYWORDS:** Evaporative Cooling, Chimney, Entrainment, Nozzle & CFD*

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Original Article

INTRODUCTION

A multi-stage Down-draft Evaporative Cool Tower (DECT) is one component for air conditioning of building by employing air blow passing the building. The use of this component is considered environmentally friendly and there is no electric required. Basically the multi-stage model is the development from the predecessor single stage model to improve the performance. Some design and investigations were reported in various publications, such as in experiment [1, 2, 3] also by using a simulation CFD approach [4, 5, 6]. In order to improve the cooling effect, additional water spray from the nozzle into the chimney can be useful [7]. The water spray gives better cooling effect compared with the use of natural airflow only. The misting process or spraying water is produced by nozzle configuration inside the chimney.

Gant [8] reported simulation results of single spray by using CFD. The water spray, the thermal energy transfer and momentum occurred between spray and ambient air was numerically simulated. Gant [8] investigated a model of vertical cylinder diameter of 1m and a length of 1.5m, using a single nozzle vertically downward positioned at the upper location of the cylinder. Meanwhile the nozzle model was a small cylinder with a diameter of 0.00625 m and a length of 0.05m. The usage of the CFD numerical tool was previously validated and tested by comparing simulation results with experiments [9], showing that simulation results were comparable with that from experiments. Tambur and Guetta [10] also reported their work used two commercial nozzles of Bete PJ32

and TF6 from their experiment. Each nozzle was varied in orifice diameter as many as 16 variation pressures. The results indicate that the spray performance of PJ32 nozzle is better than TF6.

Another observation of spray was conducted by Pearlmutter et al [12] showed that the highest temperature reduction in an experimental tower of height 10m occurred when the location of the spray at 2m height. Above 2m, the temperature reduction is not significantly changed. Sarjito [14] has investigated of the tower using a number of nozzles and configuration of nozzle position to get optimum performance. Parameters investigated are mass flow rate, and uniformity velocity profile, resulted by spray nozzle effect. The arrangement of nozzles is at the same pressure, the same mass flow was balanced with number of nozzle used. The tower's height was tried in the range of 3 to 4meters. The commercial nozzle used were TF6 at working pressure of 3.33 bar, mass flow rate of air of 0.096 kg/s and spray velocity of 21.57m/s.

Two basic arrangements of the nozzles were investigated; a configuration, in which a constant radius was maintained for the nozzle pitch circle as nozzles were added, and a configuration, in which a constant spacing was maintained between all nozzles. The constant radius gave more temperature reduction and more induce mass flow rate, but, to produce this effect than the number of nozzles should be added to configuration with constant distance. The use of nozzle number 6 to 11 on arrangement constant spacing much more effective in reducing temperature and induce mass flow rate. The best performance of cooling was arranged with 9 nozzles and effective mass flow rate number found when using 10 nozzles. Further study, when one nozzle added at the center give more entrainment mass flow, therefore the use of 11 nozzles was selected.

Further research extending to multi-stage was conducted by Sarjito and Marchant [15] to establish a baseline performance of cooling towers. The main parameter was the secondary to primary mass flow ratio. This work presented the use of Computational Fluid Dynamics (CFD) to optimize the geometry of a multi-stage evaporative cooling device. In particular, the effects on the performance of varying the primary inlet to mixing stack area ratio. Contour plots of temperature and RH at the cooled space and the velocity profile at the outlet of the device were representative of real conditions as being the un-evaporated water and sensible cooling power. Comparison of the simulated and calculated results showed good agreement.

The improvement of the performance of multi-stage downdraught evaporative coolers was studied and simulated by employing CFD analysis then verified experimentally [16]. The preliminary CFD work focused on establishing the correlation between environmental wind velocity and the downdraft quantity and comparing the result with the secondary experimental data. The detailed flow features that did not available from experiment was shown and drawn numerically on CFD. The numerical results extended the spraying model both of numerical and experimentally conducted by Gonzales-Tello et al [17].

This current research presented in this paper investigated alternative nozzle arrangement design for ease and better temperature distribution and velocity profile in the chimney, also searching for a better level of Relative Humidity (RH). The research was carried out computationally using Computational Fluid Dynamics (CFD).

METHODOLOGY

Existing Nozzle Arrangement

An existing experimental chimney with its nozzle arrangement was previously developed [13]. Two types of nozzle arrangement were available. In the first model, nozzles were going around the circle with constant

radius 0.65 meters. The nozzles in the second model were scattered with constant distance between the nozzles 0.65 meters.

Figure 1 shows the nozzle arrangement consisting 11 nozzles. One nozzle is located at the center of the chimney's axis and the other ten nozzles are at radius 0.75m with the distance in between 0.65m.

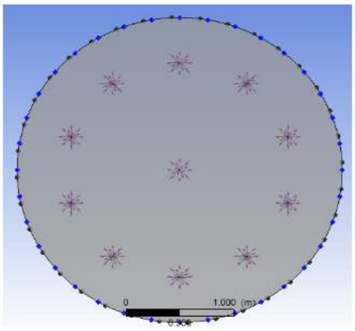

Figure 1: Eleven Nozzle Arrangement

The illustration of the chimney and the height location of the nozzles are shown in the Figure 2.

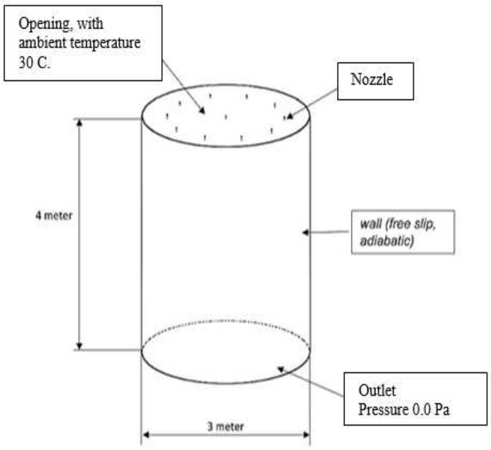

Figure 2: Chimney and Nozzle Location

Meshing Sensitivity

In computational analysis, element meshing is very important to obtain accurate results. Five element meshing design was prepared. Simulations were conducted for all meshing types and compared with the existing design. The closest meshing model was then selected for further analysis. The meshing models indicated as mesh A, B, C, D, and E are illustrated in the Figure 3.

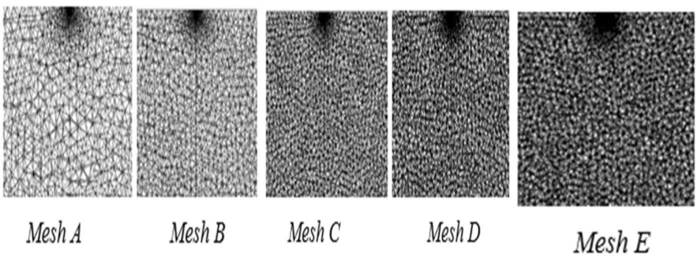

Figure 3: Chimney and Nozzle Location

The comparison information of the meshing types in regard the number of nodes and elements are depicted in the Table 1.

Table 1: Meshing Properties Comparison

Type	Mesh A	Mesh B	Mesh C	Mesh D	Mesh E
Min. size	0.006	0.004	0.0029	0.0014	0.00085
Max. size	0.11	0.08	0.05	0.05	0.045
Nodes	90639	204853	348068	353747	485360
Elements	515220	1179441	2016345	2049022	2820115

Study on Nozzle Configuration

In order to improve the performance of the nozzles. Several configurations were tried to replace the eleven nozzle arrangements in one layer. The alternative configurations have the same number of nozzles, but the location is different. Three configurations were tried.

4 Nozzles on Top and 7 Nozzles at the Lower Layer

Seven nozzles were tried in 6 alternative heights from the bottom: 1m, 1.5m, 2m, 2.5m, 3m and 3.5m. The illustration of the models is illustrated in the Figure 4.

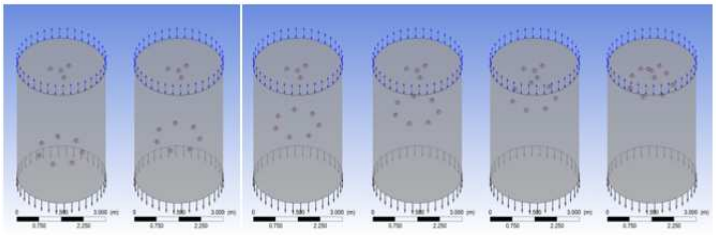

Figure 4: Nozzle Configuration 4-7

6 Nozzles on Top and 5 Nozzles at the Lower Layer

Six nozzles were tried with 6 alternative heights from the bottom: 1m, 1.5m, 2m, 2.5m, 3m and 3.5m. The illustration of the models is illustrated in the Figure 5.

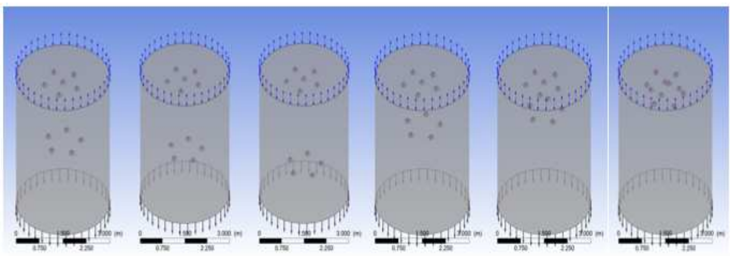

Figure 5: Nozzle Configuration 5-6

8 Nozzles on Top and 3 Nozzles at the Lower Layer

Three nozzles were tried with 6 alternative heights from the bottom: 1m, 1.5m, 2m, 2.5m, 3m and 3.5m. The illustration of the models is illustrated in the Figure 6.

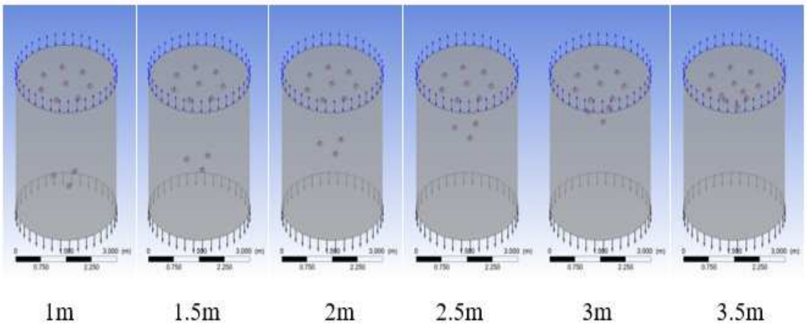

Figure 6: Nozzle Configuration 8-3

11 Nozzles in Helical Pattern

Eleven nozzles were arranged in a helical pattern as seen in the Figure 7. The nozzles followed the rotating helical configuration.

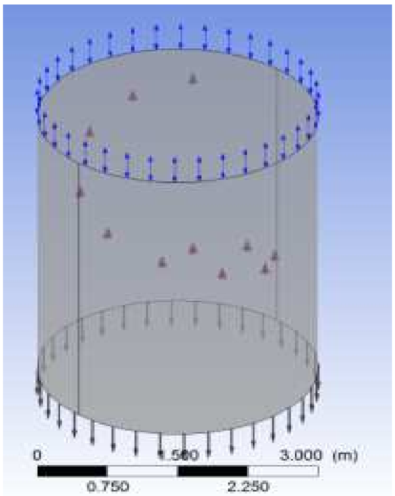

Figure 7**: Nozzle Helical Configuration**

RESULTS AND DISCUSSIONS

Meshing Selection

Five meshing models were tested and compared against the experimental results previously conducted, taken from [13]. The comparison of simulation results from mesh A, B, C, D and E and the experiment is shown in the Table 2 and plotted in the Figure 8.

Table 2: Meshing Comparison with Experiment

Measurement Level From Top of Tower (m)	Temperature (K)					
	Sarjito [13]	Mesh A	Mesh B	Mesh C	Mesh D	Mesh E
0	300.93	299.343	300.181	300.699	300.888	301.113
0.95	301.461	300.868	300.938	301.695	301.749	301.766
1.95	302.404	301.557	301.613	302.391	302.361	302.402
2.95	303.054	302.256	302.294	302.856	302.847	302.868
3.95	303.15	303.143	303.145	303.146	303.147	303.148

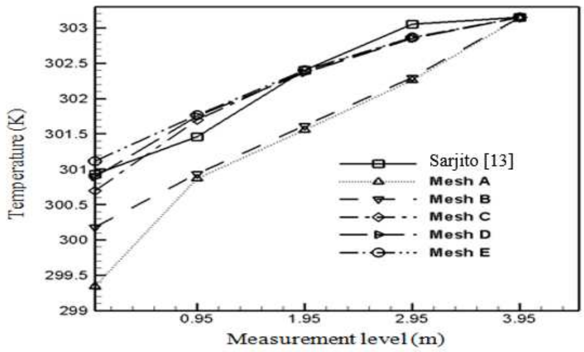

Figure 8: Temperatures on Various Meshing

The comparison results (Table 2 and Figure 8) indicates that the simulation results using mesh size A, B, C, D and E show a comparable pattern with previous study from [13]. Meshing C however directs to the closest data with those from experimental data. It is therefore decided to use meshing C type for other analysis.

Nozzle Configuration 4-7

The position of seven nozzles in the lower layer at height levels were 1m, 1.5m, 2m, 2.5m, 3m and 3.5m, represented by Zmax-Z1, Zmax-Z2, Zmax-Z3, Zmax-Z4, Zmax-Z5 and Zmax-Z6 respectively. The temperature comparison results are shown in the Figure 9.

Figure 9 shows that reducing temperature was best achieved at position Zmax – Z6 where 7 nozzles are at the height of 3.5m from the ground. In this position, the distance of upper and lower nozzles is 0.5m. The recorded temperature reduction is 2.454^{o}C or about 8.18% reduction.

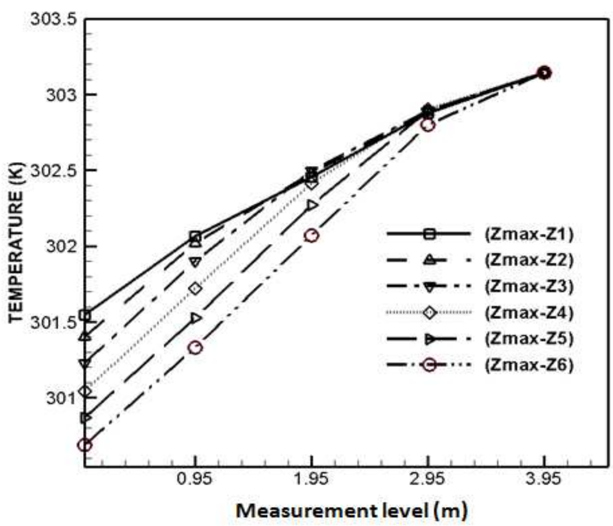

Figure 9: Temperatures of 4-7 Nozzle Configuration

Nozzle Configuration 6-5

In this configuration, 5 nozzles were positioned at 1m, 1.5m, 2m, 2.5m, 3m and 3.5m and indicated as Zmax-Z1, Zmax-Z2, Zmax-Z3, Zmax-Z4, Zmax-Z5 and Zmax-Z6 respectively. The simulation results are plotted in Figure 10.

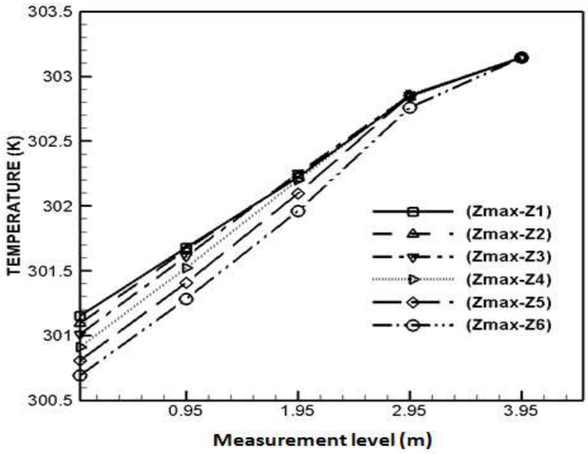

Figure 10: Temperatures of 6-5 Nozzle Configuration

By considering the simulation results shown in the Figure 10, it is found that the lowest temperature reduction occurred when the 5 nozzles at the level of 3.5 m from the ground (Zmax–Z6). In this configuration the temperature reduction can be achieved as high as 2.45^{o}C or decreased by 8.17%

Nozzle Configuration 8-3

Three nozzles were tried at the level of 1m, 1.5m, 2m, 2.5m, 3m and 3.5m from the ground, represented by Zmax-Z1, Zmax-Z2, Zmax-Z3, Zmax-Z4, Zmax-Z5 and Zmax-Z6 respectively. The simulation results are plotted in Figure 11.

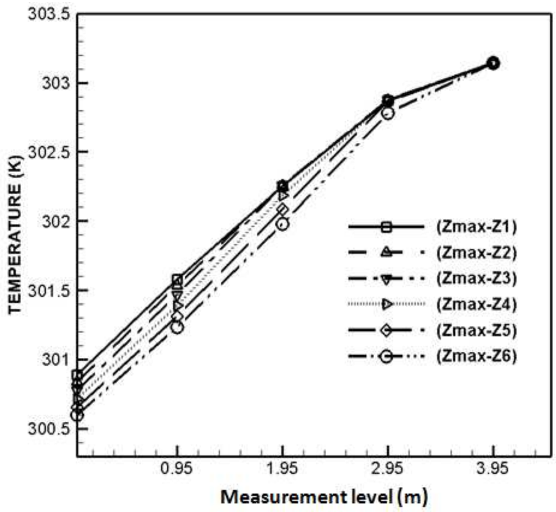

Figure 11: Temperatures of 8-3 Nozzle Configuration

The results from the Figure 11 show that when the three nozzles are at the height of 3.5m from the ground, the temperature can be reduced 2.55^{o}C or declined by 8.17%. This reduction is almost similar to that achieved from 4-7 configuration.

Nozzle Configuration 11 Helical Patterns

Eleven nozzles were configured helically using constant space from top layer to lower layer 0.5 from the ground. There was no nozzle in the center. The temperature distribution in different level can be seen in the Table 3.

Table 3: Temperature Distribution 11 Helical Nozzles

Level from Top (m)	Temperature (K)
0	300.21
0.95	301.58
1.95	302.50
2.95	302.98
3.95	303.15

It can be seen from Table III that helically nozzle configuration resulting highest temperature of 303.15^{o}K and the lowest temperature of 300.21^{o}K. The temperature reduction can achieve as high as 2.94^{o}C or about 9.8% reduction.

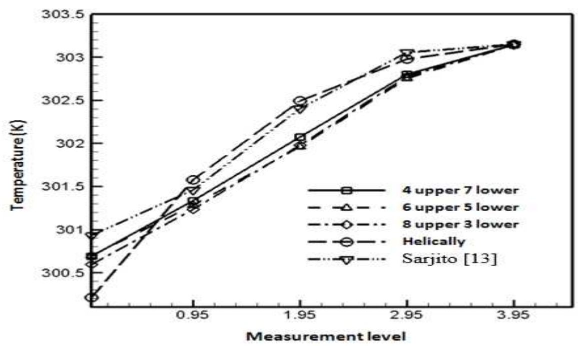

Figure 12: Comparison of All Configurations

Selection Nozzle Configuration

The comparison of all configurations is summarized and plotted in the Figure 12. The comparison chart shows that nozzle configuration resulting lowest temperature reduction was 8 nozzles on top and 3 nozzles at lower position or (Zmax–Z6). The temperature reduction at lower plane is 2.55^{o}C.

Effect of Nozzle Configuration to Entrainment

Further study in conjunction with the nozzle configuration to temperature was the entrainment mass flow of air inside the tower itself. The air velocity distribution for all configuration investigated is shown in the Figure 13.

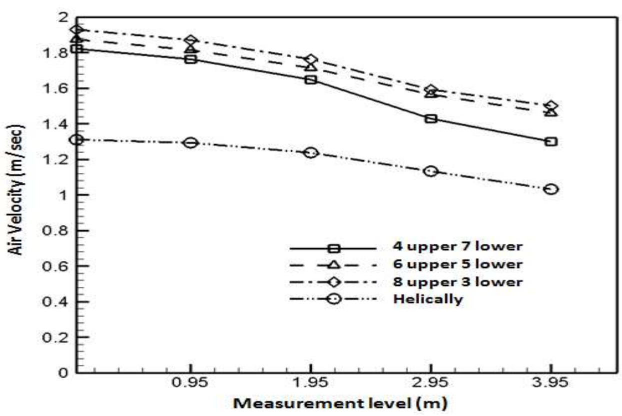

Figure 13: Comparison of Air Velocity and Nozzle Configuration

Based on Figure 13, it is convinced that air velocity inside the tower was increasing along with an additional nozzle on top of the tower. The more nozzles used then mass flow rate increased accordingly, as velocity and quantity of the mass flow rate entrained will be increased.

CONCLUSIONS

This work was searching the optimal configurations of array nozzle spray and its effect particularly to the temperature reduction in cooling tower by using computational fluid dynamics simulation tool.

The simulation results show that nozzle configuration resulting lowest temperature reduction was 8 nozzles on top and 3 nozzles at lower position or (Zmax – Z6). This mode gives temperature reduction at a lower plane of 2.55°C compared to other configurations.

Further study proved that air velocity inside the tower was increasing along with an additional nozzle on top of the tower. The more nozzles used then mass flow rate increased accordingly.

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